Aerospace Mission Failure Analysis for NASA Ames Research Center Design for Safety initiative

September 30, 2001

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This study was performed by The Aerospace Corporation for the NASA Ames Research Center under the direction and guidance of Mr. Michael Gaunce, Program Manager.

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Table of Contents

- Overview
  - Team
  - Mission Failure Analysis Flow Chart
  - Critical Failure Data Analysis Process
- Results Summary
  - What & Why cause distributions for all failures
  - Future Trends

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Overview

- The purpose of this study is to provide NASA Ames with an evaluation of all launch vehicle and space vehicle critical failures from 1986 thru 2000 per a taxonomy supplied by Ames after contract award.
- Critical failure is defined to be those failures that resulted in a premature or unanticipated catastrophic loss of the vehicle.
- Aerospace added meta data fields in addition to the what and why cause categories supplied by Ames to help the data sorting process by vehicle types. (see appendix B)
- Aerospace Corp Space Systems Engineering Data Base (SSED), Industry Failure Investigation Reports, Aerospace Failure Summary Reports, BAR investigation reports, news articles and web sites were used to investigate 137 critical failures per the Ames taxonomy. The available cause data was sufficient to analyze 84 failures per the Ames Taxonomy.(see appendix C & D)

The Aerospace Corporation Team

- **Team Members**

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Mission Failure Analysis Flow Chart

1.Identify LV & SV Catastrophic Failures

- # LV Failures
- # Orbiting SV Failures
- # Deep Space/planetary SV Failures

2.Identify & Analyze All Failure Analysis Reports

- Investigation Board Reports
- Anomaly Reports
- Web/news Media Reports
- Personnel Interviews

3.Assign Root Cause to D fS Supplied Taxonomy Items

- What Occurred
  - Hardware, Software, Etc.
- Why it Occurred
  - Mgmt, Design, Test, Etc.

4.Evaluate Root Cause Results

- LV/ Orbiting/deep Space SV/reusable
  - Commonality/Differences
  - Any Common Modes Drivers
  - Environment Drivers

5.Develop Excel Database

- Classify Failures Per Taxonomy
- Organizational Effects
- Human Factors Effects
- Design Effects
- Etc.

6.Document Results

- Draft Report
- Final Report
- Final Populated Excel Database

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Critical Failure Data Analysis Process

- Sort of SSED Data Base for critical failures from 1986-2000 imported into Excel Spreadsheet.
- Ames taxonomy data fields added to meet DfS needs.
- Aerospace Meta Data fields added to aid statistical analysis.
- Research conducted to find any available missing detailed investigative reports (hard copy for older failures).
- Analyst reviews SSED data, investigation report, summary report and other available data for each critical failure.
- Appropriate What Data Fields selected per Ames Taxonomy
- Causes and types: 1) Proximate (most probable), 2) Root and 3) contributing are identified where possible.
- Appropriate Why Data Fields selected per Ames Taxonomy for each cause type:
  - For some causes the why is clear; for others, judgement of the analyst is required.
  - An independent review of data is used to validate results.

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Study Results Summary

- For all failures the top three subsystem contributors are Propulsion (44%), Guidance Navigation & Ctrl (28%) and Electrical Power (17%)
- For Launch Vehicles the top three subsystem contributors are Propulsion (58%), GN&C (22%) and Electrical power (11%)
- For Space Vehicles the top three subsystem contributors are GN&C(),Electrical Power() and Telemetry Tracking & Cmd()
- For all failures the top four cause contributors are Design (12%), Procedures (10%), Task Perf (8%), & Quality Ctrl (8%)
- For Launch Vehicles the top four cause contributors are Procedures(12%), Inspection(11%), Design(10%), & Quality Control (10%)
- For Earth Orbiting SV the top cause is Design(15%): Deep Space SV is Management (23%): Reusable SV is QC(14%)

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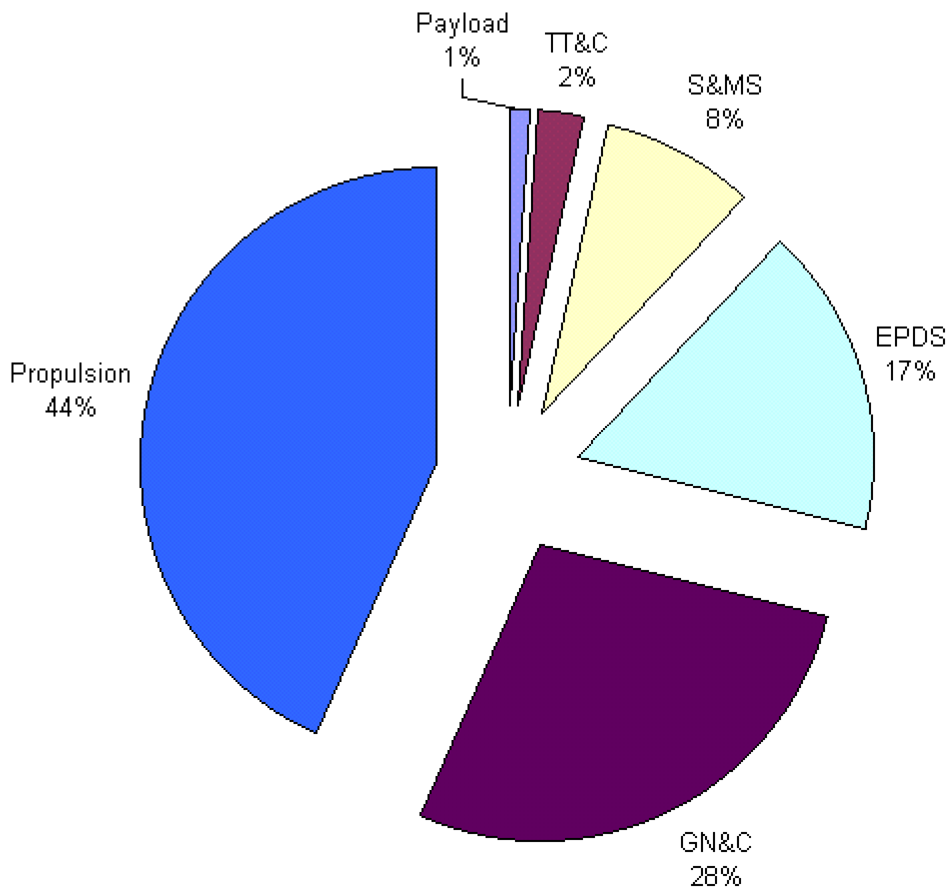
Percentage Distribution of What Subsystem Failed for All Vehicles



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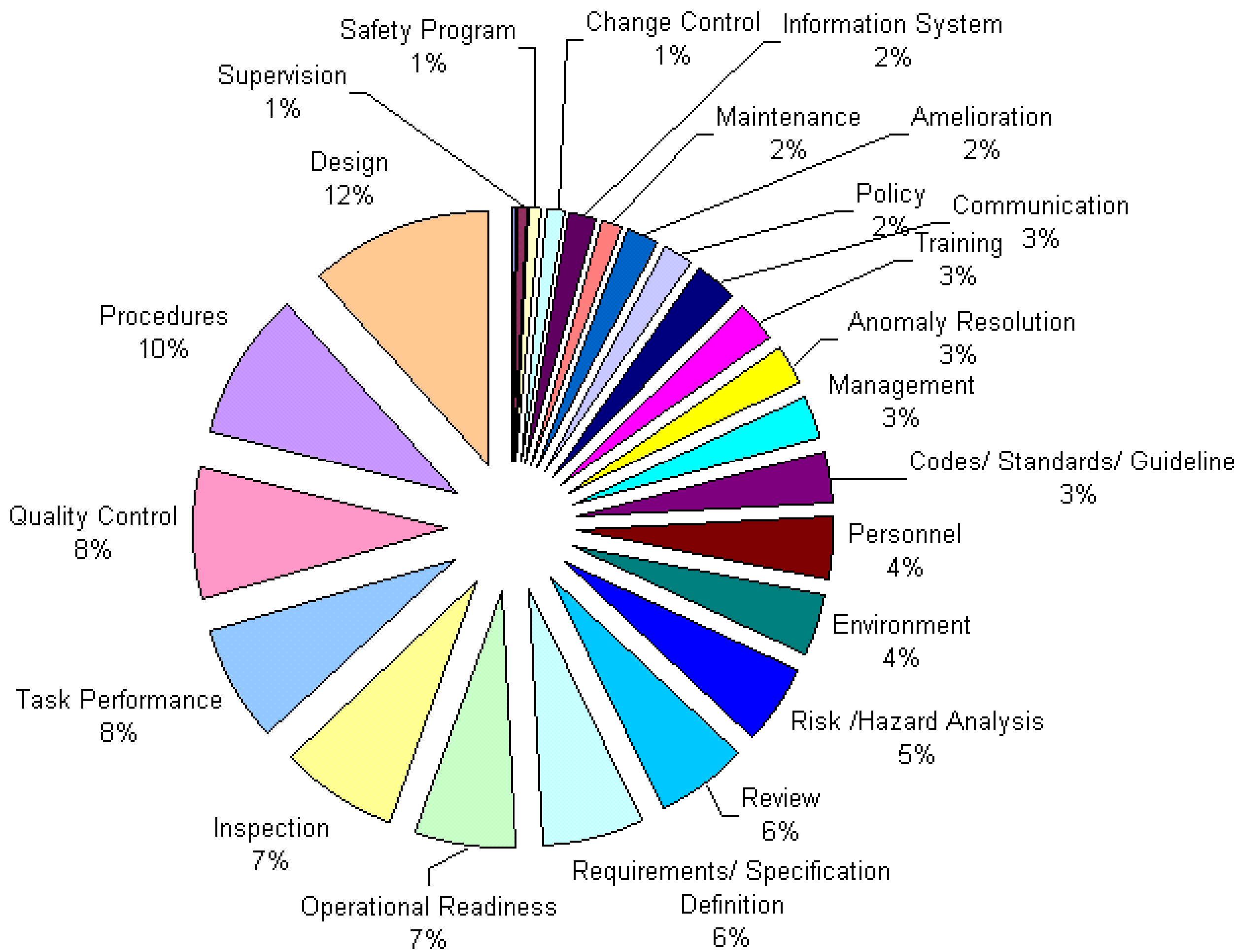
WHY Percentage Distribution of All Failures



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LAUNCH VEHICLE STAND DOWNS (1986-2000)

Vehicle	Tail No.	Payload	Failure Date	Return to Flight Date	Stand Down (Months)	Flt History	Average Flt Rate per Year
STS	51-L	TDRS-B/IUS	1/28/1986	9/29/1988	32	75/1	5
Titan 34D	D-9	DOD	4/18/1986	10/26/1987	18	7/2	n/c
Atlas	AC-67	FLTSATCOM 6	3/26/1987	5/15/1987	2	78/4	5
Delta	#178	GOES-G	5/3/1986	9/5/1986	4	102/5	7
Titan IV	K-11 NUS	DOD	8/2/1993	2/7/1994	6	29/4	2

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ANTICIPATED TRENDS OF FUTURE TECHNOLOGIES ON SPACE SYSTEM RELIABILITIES

DESIGN &ANALYSIS PROCESSES

- GREATER INTEGRATION OF MULTISYSTEM DESIGN/ANALYSIS TOOLS
  - BETTER UNDERSTANDING OF SYSTEM INTERACTIONS
- UBIQUITOUS APPLICATION OF PSD AND PRA
  - BETTER UNDERSTANDING OF RISK
- MORE AUTOMATION IN DESIGN TOOLS WITH INADEQUATE CAPTURE OF EXPERIENCE BASES
  - LOSS OF PHSYICAL INSIGHT INTO FAILURE PHENOMENA
- BETTER UNDERSTANDING OF ADVANCED MATERIALS AND PROCESSES
  - PRESSURE TO REDUCE SAFETY MARGINS

MANUFACTURING AND ASSEMBLY PROCESSES

- MORE AUTOMATED FABRICATION AND QA
  - AUTOMATED MANUFACTURING STATISTICAL PROCESS DATA BASE
  - ENHANCED HERITAGE TRACEABILITY
- WIDER DISTRIBUTION OF MANUFACTURING & QA RESPONSIBILITY
  - LESS QA CONTROL
- MORE COMMERCIAL PRACTICES
  - MORE FOCUS ON COST/ RELIABILITY TRADEOFFS

ANTICIPATED TRENDS OF FUTURE TECHNOLOGIES ON SPACE SYSTEM RELIABILITIES

NEW MATERIALS

- HIGHER TEMERATURES, STRESSES, LIFETIME REQUIREMENTS; LOW SERVICING REQUIREMENTS, ENVIRONMENTAL LIMITATIONS
- GREATER USE OF CERAMICS, COMPOSITES
  - INHOMOGENEOUS, NONISOTROPIC , ADAPTIVE, SELF-HEALING, “SMART” MATERIALS
  - MORE DIFICULT TO CHARACTERIZE AND CERTIFY
  - POSSIBLY MORE DIFFICULT TO MONITOR CONDITION

INTEGRATED VEHICLE HEALTH MANAGEMENT

- AUTONOMOUS SYSTEMS CAPABLE OF MITIGATING TECHNICAL *AND HUMAN-FAULT-DRIVEN ANOMALIES.*
  - NEW APPROACHES TO CERTIFICATION
  - KEY TO AIRLINE-TYPE OPERABILITY
- IVHM SYSTEMS COUPLED TO AUTONOMOUS SPACE SYSTEMS CONTROLLERS FOR DEEP SPACE MISSIONS
  - NEW LEVELS OF RELIABILITY REQUIRED WITH VALIDATION CHALLENGES
- CONCURRENT DESIGN OF SYSTEM & IVHM

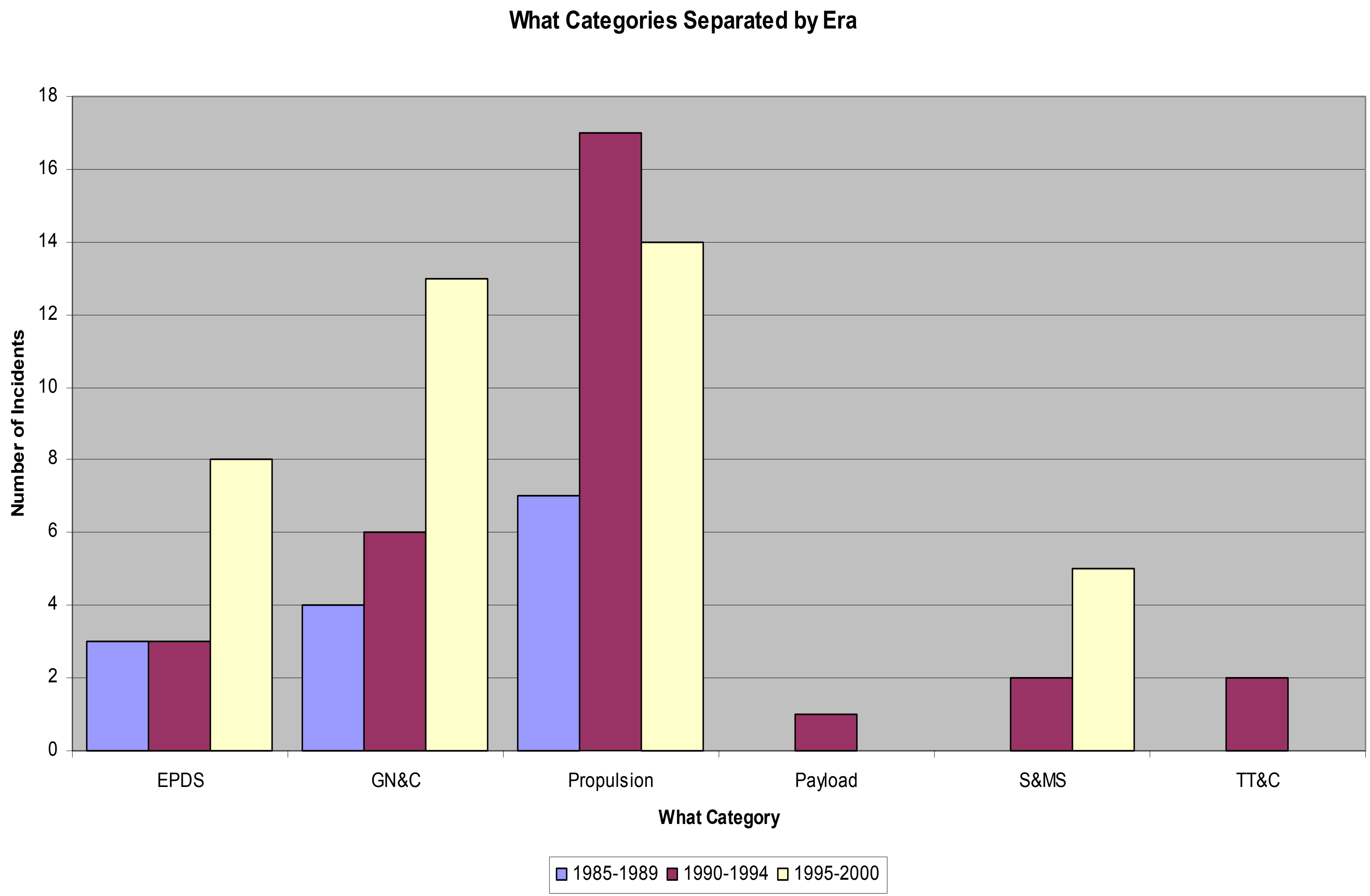
ANTICIPATED TRENDS OF FUTURE MISSIONS/ REQUIREMENTS ON SPACE SYSTEM RELIABILITIES

LAUNCHERS

- HIGH OPERABILITY/ QUICK TURNAROUND/ ON-DEMAND CAPABILITY
  - RELIABILITYCAN NO LONGER DEPEND ON TIME AND MANPOWER-INTENSIVE CHECKOUT
  - AUTOMATED CHECKOUT AND CONDITION MONITORING COULD SIGNIFICANTLY REDUCE HUMAN ERROR-CAUSED FAILURES
  - COMMERCIAL PRACTICES COULD SHORT CHANGE QA
- MORE SEVERE ENVIRONMENTS ASSOCIATED WITH FUTURE RLV'S (ESP. Gen3) WILL PROBABLY PROVIDE ADDED RELIABILITY/SAFETY CHALLENGES

PAYLOADS & SPACECRAFT

- UNMANNED AND MANNED LONG DURATION SPACE MISSIONS WILL NEED NEW LEVELS OF RELIABILITY, AUTONOMY AND ATTENTION TO DETAIL
  - HIGH COST OF RELIABLE, AUTOMATED CERTIFIED SYSTEMS FOR ONE-OF-A-KIND SPACECRAFT
- AUTOMATED IN-SPACE REPLENISHMENT AND REFURBISHMENT OF SPACE SYSTEMS (ORBITAL EXPRESS, ETC.) MUST BE PERFORMED SAFELY



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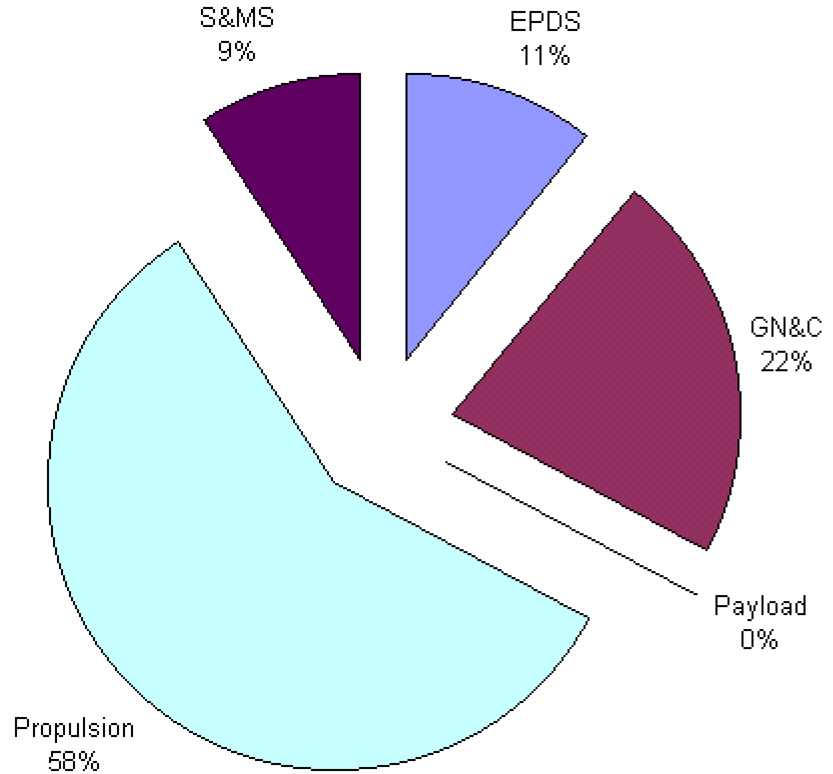
Failed Subsystem Percentages for ELVs



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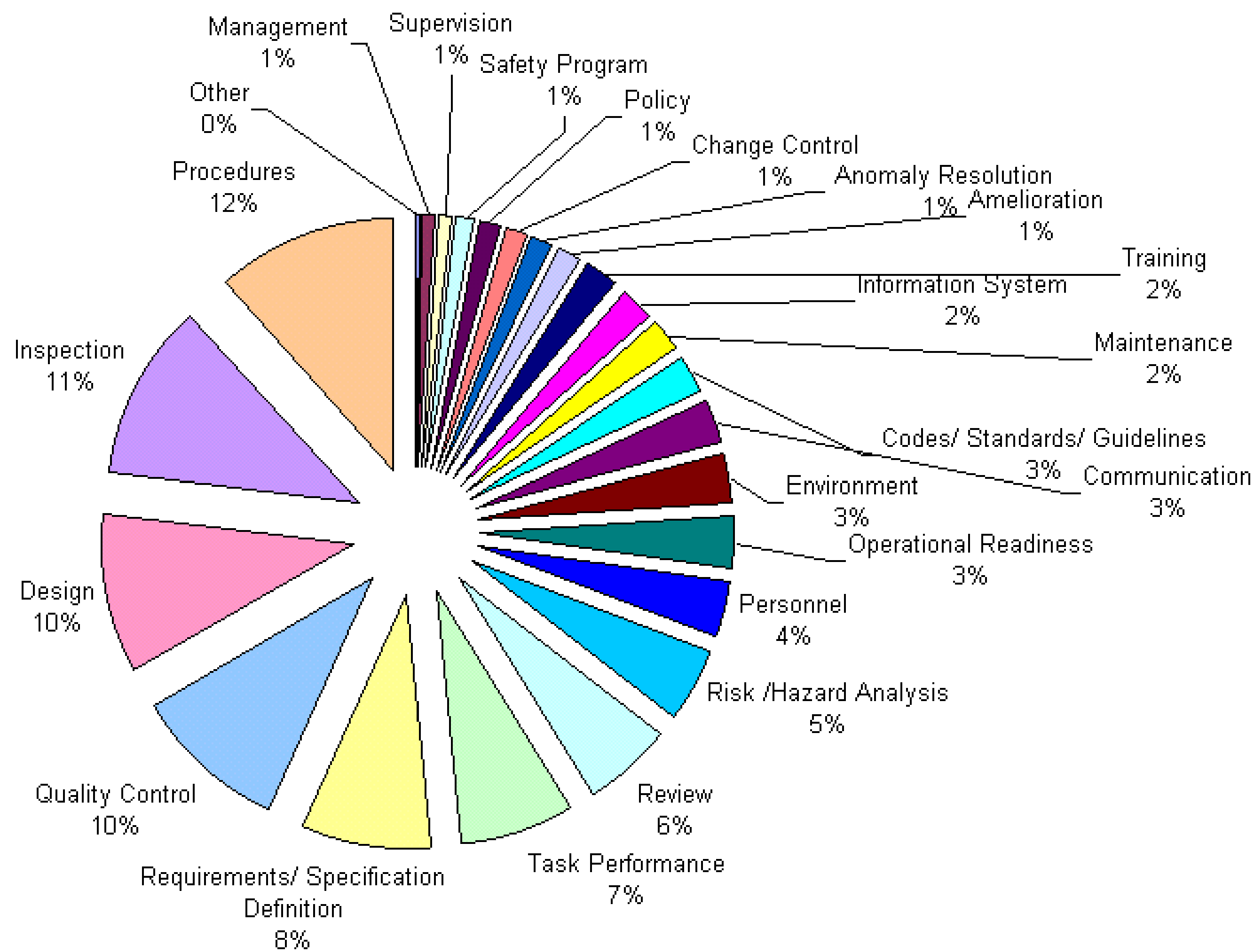
Why Percentage of Failure Distribution for ELVs



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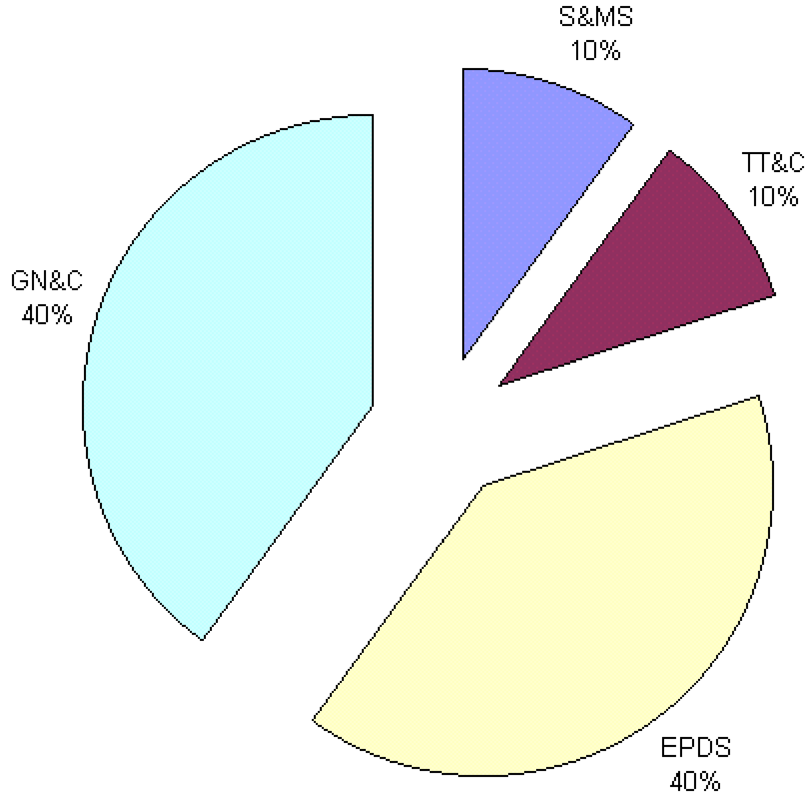
Percentage of Subsystem Failures for Earth Orbiting Vehicles



Population of Vehicles : 20

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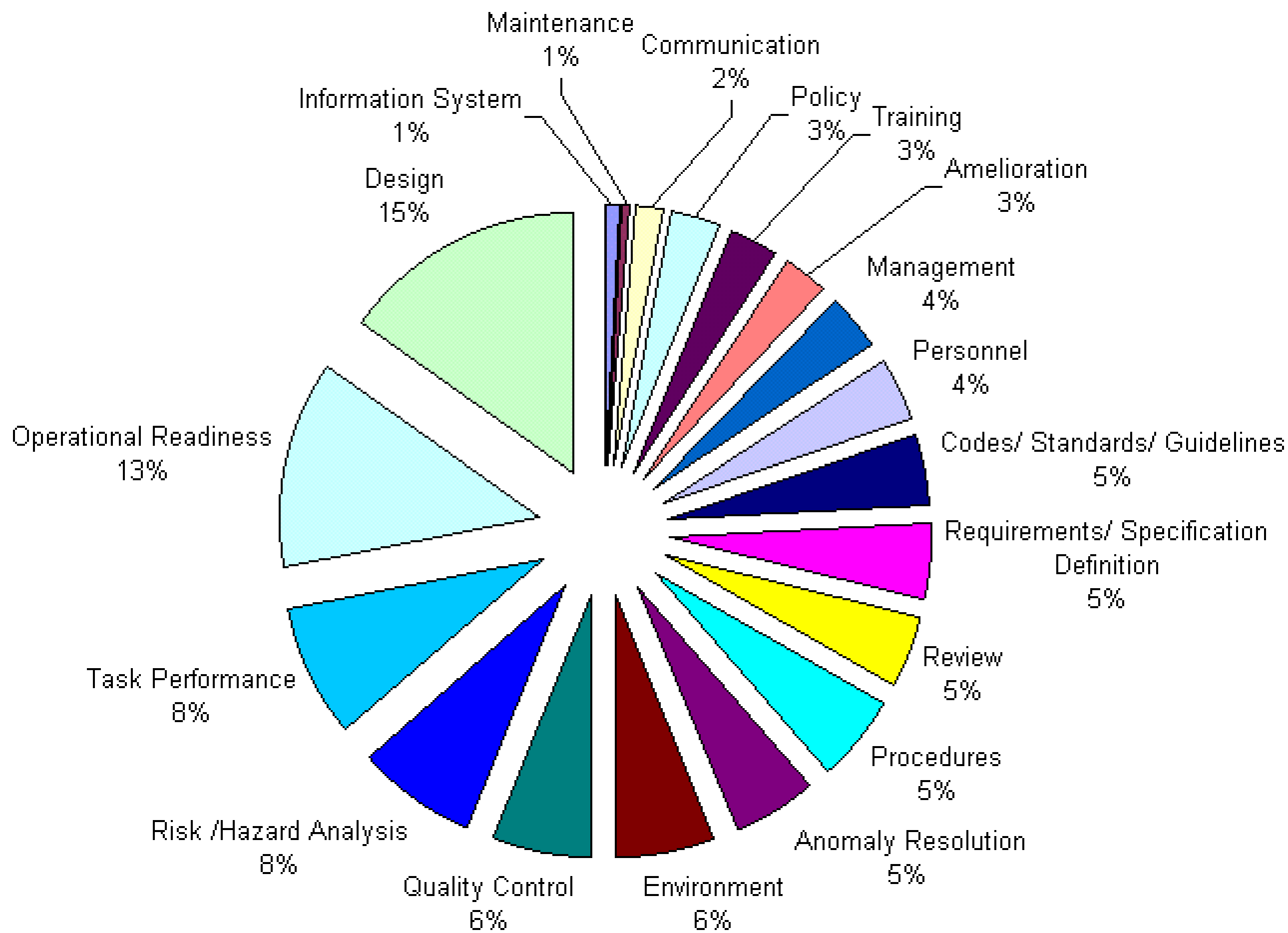
Percentage Causes for Earth Orbiting Vehicles



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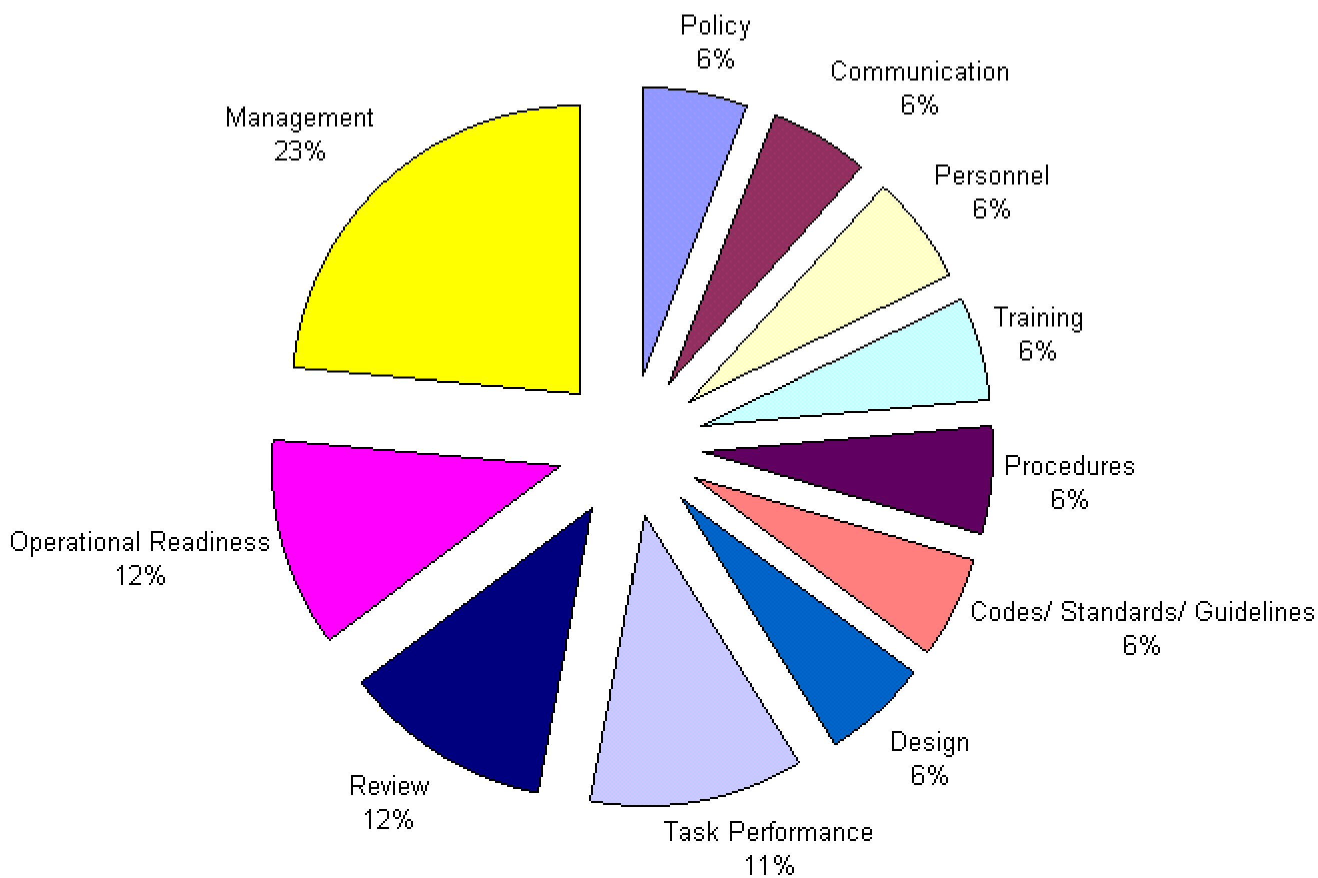
Percentage Causes for Deep Space Vehicles



Note: 3 EDS failures identified, all attributed to GN&C

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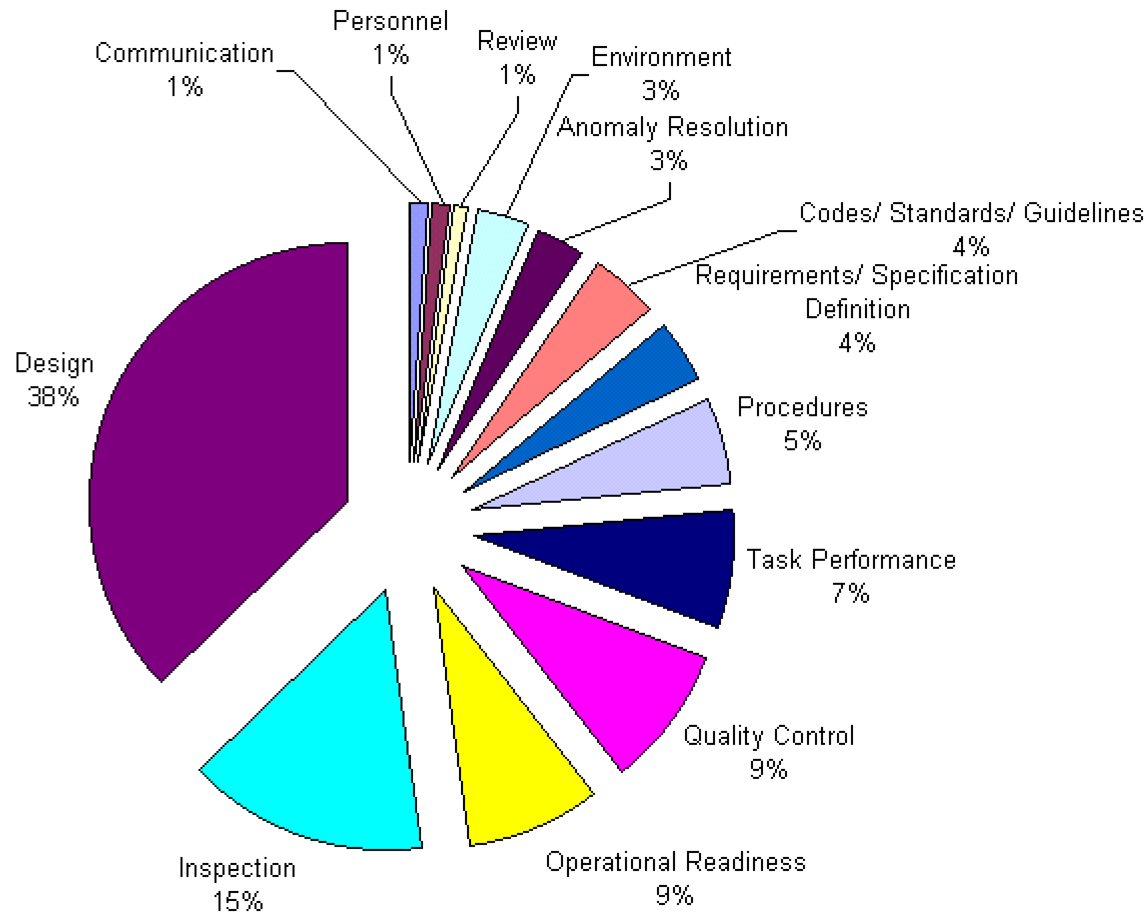
Cause Type Definitions

- Reported Proximate Cause: Occurrence or factor from which incident is directly precipitated
- Reported Root Cause: Systemic Factor that causes or creates conditions that resulted in incident
- Reported Contributing Cause: Circumstance, environment or condition that worked to allow, encourage, or exacerbate the incident

Percentage Distribution of Proximate Causes



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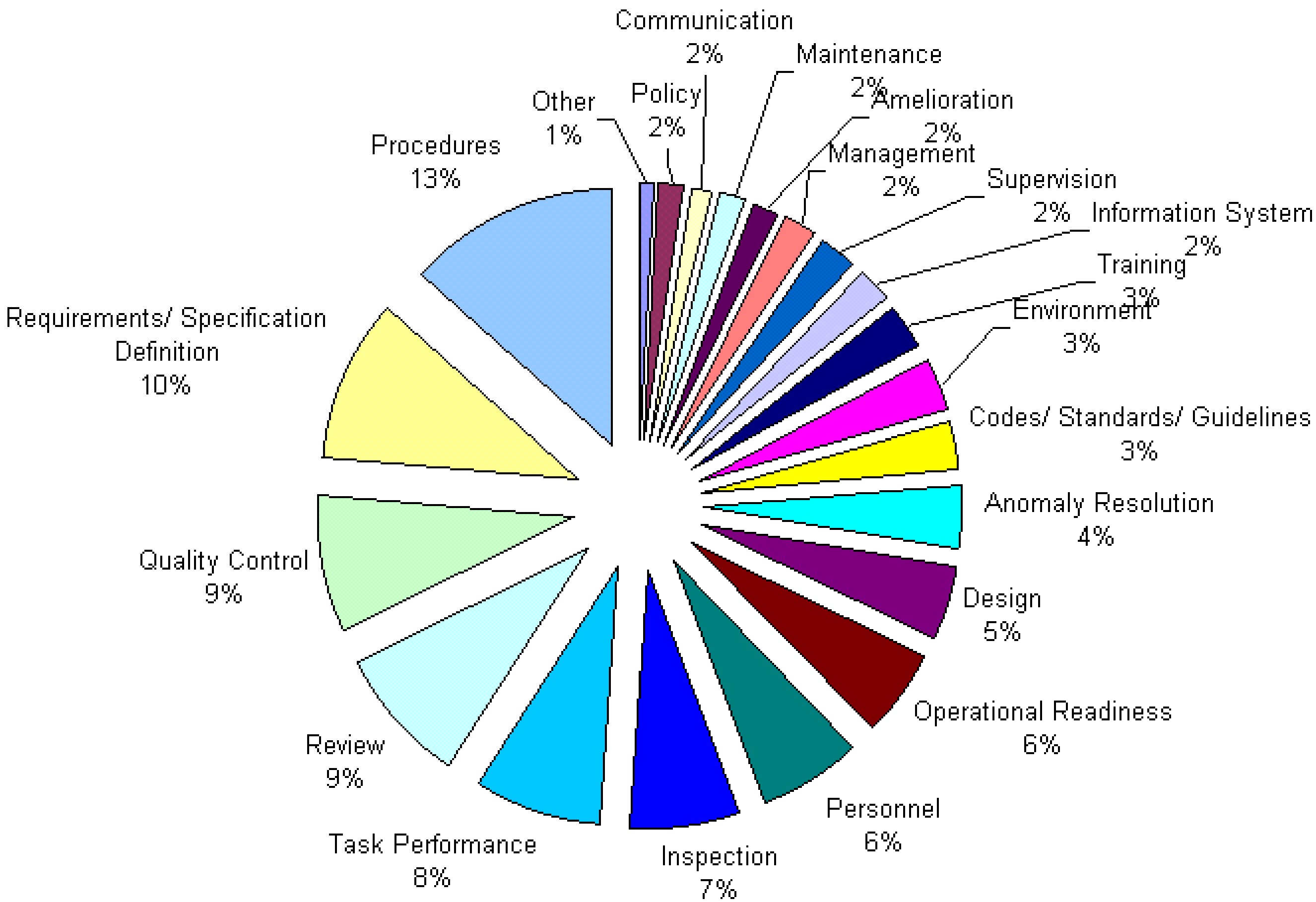
Percentage Distribution of Root Causes



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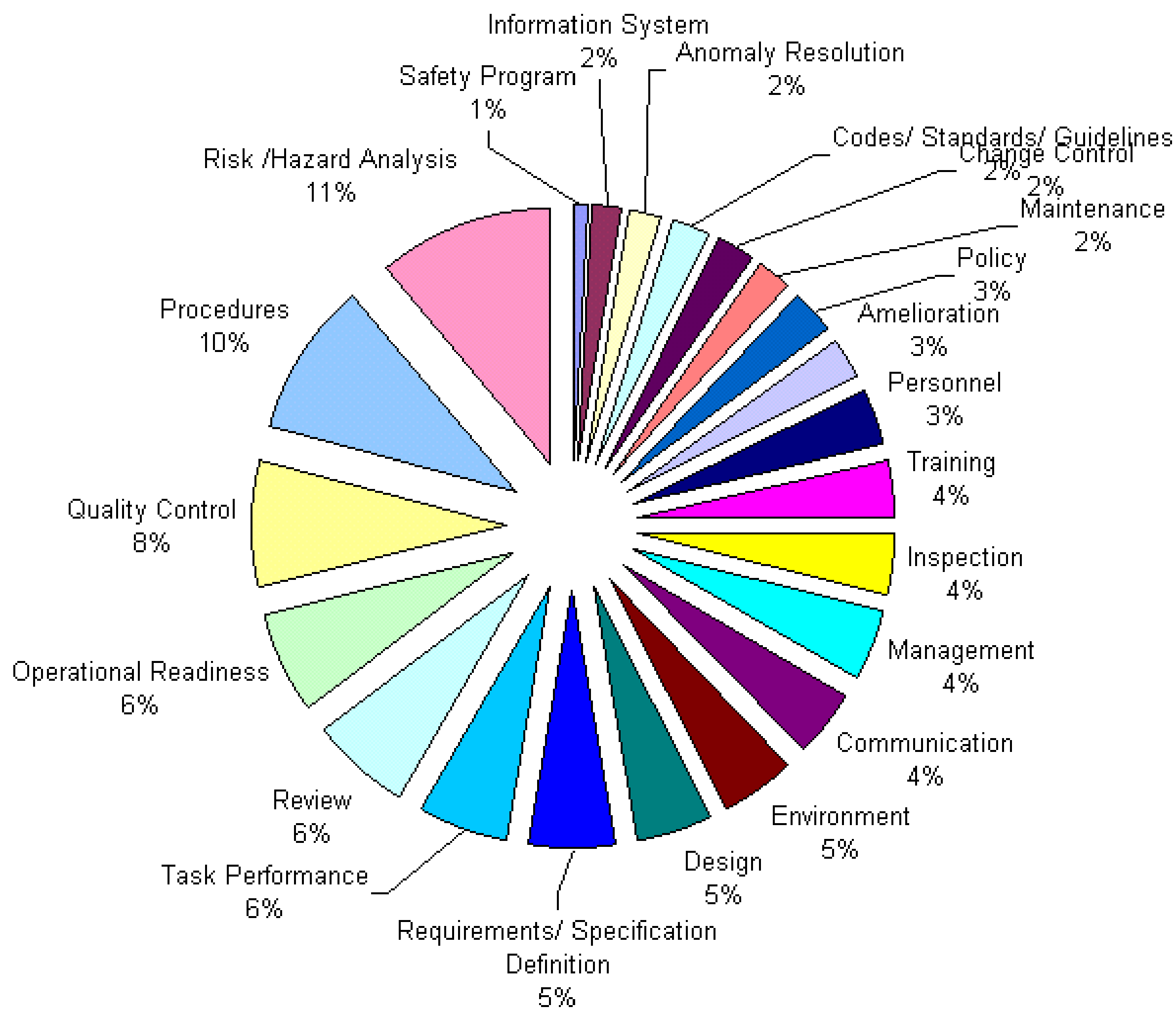
Percentage of Contributing Causes



Failure Summary Status

	# Fail	Gov	Non-Gov	# Rpts	# Summ	# Other
Launch Vehicles						
US LV		24		17	6	1
Foreign LV			50	5	14	31
Total	**74**	**24**	**50**	**22**	**20**	**32**
Space Vehicles						
Foreign SV			15	0	4	11
US Non-Gov SV			31	0	14	17
US Civil SV		11		11	0	0
US DoD SV		6		3	1	2
Total	**63**	**17**	**46**	**14**	**19**	**30**
Grand Total	**137**	**41**	**96**	**36**	**39**	**62**

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